# Exploring Interactions at the Fe-GaAs Interface

The change in magnetic properties of films when the substrate morphology changes is of great interest. To investigate this in detail, we undertook a study of Fe thin films grown on GaAs surfaces of differing morphology. Using high-resolution Fe L-edge spectroscopy at the Advanced Photon Source, we were able to study changes in the unoccupied electronic states of Fe atoms. Analysis of the Fe L-edge absorption spectra has provided a measure of the transfer of 3d charge from the Fe to Ga and As atoms in the substrate. Another interesting facet of this result is that the intermixing and surface roughness does not dramatically alter the 3d charge transfer.

Semiconductor-based electronics have been the standard for several decades, but, in the past decade, there has been an explosion of research into novel structures based on spin ("spintronics") [1], in which one can use the spin degree of freedom as an additional handle for the modification of electron transport to produce spin-based electronics [2-4]. Applications include nonvolatile magnetic random access memory, spin transistors, and high-sensitivity sensors. Given these new devices, one would like to fold them into semiconductor-based systems, but the integration process is fraught with several barriers that must be overcome. Interfacial intermixing commonly found at metal-semiconductor interfaces degrades properties of the magnetic devices and needs to be better understood.

Iron on GaAs was one of the first ferromagnetic-semiconductor systems studied due to the lattice match for growth of single-crystal structures (see Fig. 1). Up to this point, studies have focused on the GaAs surface structure to determine if the unique magnetic properties of the overlayer are related to the details of the GaAs surface on which the films were prepared [5-8]. For thicknesses less than 5 monolayers (ML), all systems are found to be magnetically inactive, while thicker films ferromagnetically order and display a strong uniaxial magnetic anisotropy along the (110) direction, in contrast to bulk Fe.

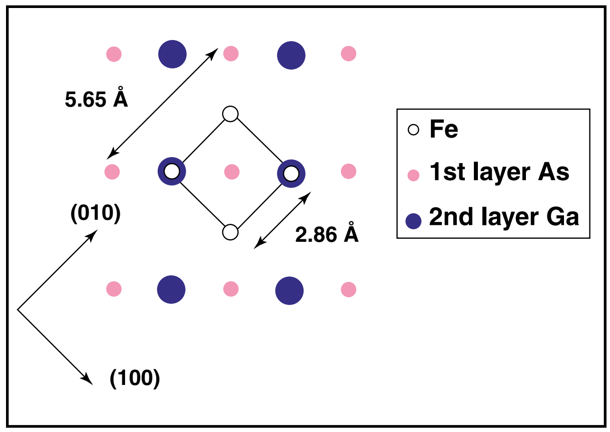


*FIG. 1. The surface structure of GaAs(100) showing the close match with the lattice of bcc Fe(100).*

To investigate this in more detail, we undertook a study of Fe thin films grown on GaAs surfaces of differing morphology. Using the high-resolution spectroscopy facilities at the Advanced Photon Source beamline 4-ID-C, we were able to study how the bonding of Fe to the GaAs surface changes the properties [9]. These x-ray-based techniques allow us to probe the details of the chemical bonding between Fe and GaAs. Changes in the unoccupied electronic states of Fe thin films provide detailed information concerning the movement of charge from one element to another.

One surprising result comes from the realization that the alloying of Fe with GaAs can be modified by the structure of the surface. It turns out that,

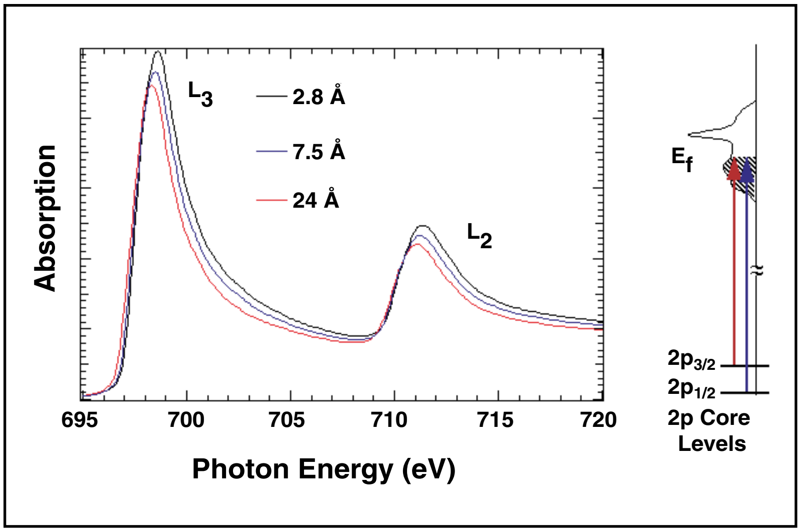


*FIG. 2. Fe L-edge absorption as a function of overlayer thickness. The diagram to the right illustrates the excitation process from the 2p core levels into the partially occupied 3d conduction band, which makes this absorption measurement sensitive to the number of 3d electrons.*

for the case of the rough (100) oriented surface, there is almost no intermixing, while the smooth (110) surface shows evidence of strong intermixing. Of most interest though in the study of magnetic materials on semiconductors is the change in the Fe overlayer. Since the 3d electrons of Fe carry the magnetic moment, any intermixing or charge transfer at the interface will alter the 3d band occupancy and directly influence the magnetic order. To determine the amount of charge transfer at the interface, Fe L-edge absorption spectra were measured as a function of overlayer coverage (see Fig. 2). Changes in the white line intensity are directly related to the 3d occupation, which shows major changes with increasing coverage.

Analysis of the Fe L-edge absorption spectra provides a measure of the transfer of 3d charge from the Fe into the substrate, as shown in Fig. 3. Note how the two systems show a similar amount of charge transfer even though preparation occurred on two uniquely different surfaces. The charge transfer is consistent with a local Fe-As bonding configuration at the interface. Due to the large difference in electronegativities, As will tend to draw charge away from Fe. Gallium has an electronegativity close to Fe, which implies that Ga could not be responsible for such a large transfer. For the (110) system, the Fe-As interface is formed using an intermixing reaction to create the desired interface with the extra surface components migrating into the Fe layer. For (100), even though no diffusion is observed, it is possible that the Ga at the interface is displaced but lacks sufficient energy to move farther than a few monolayers into the overlayer. Another interesting facet of this result is that intermixing and surface roughness do not dramatically affect the 3d charge transfer. Typically, intermixing is one of the key factors in the modification of material properties.

In conclusion, we have shown how the unique element-specific information accessible with x-ray-based techniques can provide new insight into the physics

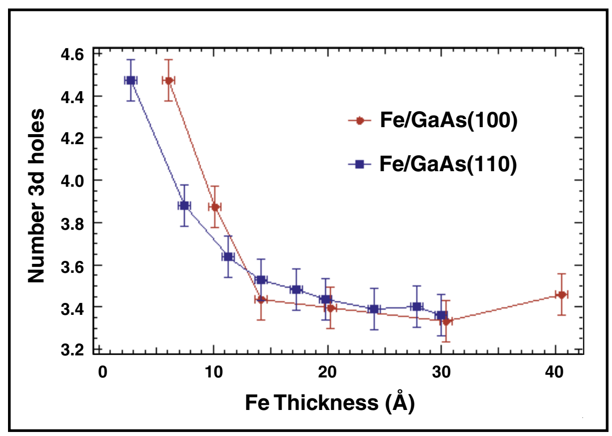


*FIG. 3. Number of 3d holes vs Fe overlayer thickness. The increase at low coverage away from the bulk value of 3.36 details the removal charge from the 3d band of Fe.*

of the metal-semiconductor interface. These results can aid in understanding how to control intermixing and the mechanism by which it might influence the magnetic properties.

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